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LONG-TERM STUDY OF *Bacillus thuringiensis* APPLICATION TO CONTROL *Tirathaba rufivena*, ALONG WITH THE IMPACT TO *Elaeidobius kamerunicus*, INSECT BIODIVERSITY AND OIL PALM PRODUCTIVITY

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ABSTRACT

A long-term study of commonly used insecticides for Tirathaba rufivena *control was conducted in Riau, Indonesia. Treatments included fipronil,* Bacillus thuringiensis *subsp. kurstaki (Btk), and a rotation of Rynaxypyr and Btk applied every two weeks for a nine-month period. Assessments were monitoring of* T. rufivena *attack, quantifying the number and activity of* E. kamerunicus, *insect biodiversity, and analysis of oil palm fruit set and productivity. Despite overlapping pest stages, all insecticides were effective in reducing* Tirathaba *larvae within four months for* Btk*-containing treatments and two months for fipronil, while* Tirathaba *attack in the untreated control initially increased and then remained persistently high. Fipronil reduced the numbers of* E. kamerunicus *weevils visiting inflorescences one month after application while* Btk*-containing treatments did not reduce weevil populations resulting in <70% and >75% fruit set, respectively. Average bunch weight in treatments, which included* Btk, *was 11.7% higher than the fipronil treated blocks and 64.5% higher than the control block resulting in a yield increase of 14.4% and 55.5% over fipronil treatments and controls, respectively.* Btk *treatments were effective in controlling* Tirathaba, *did not impact* E. kamerunicus *or overall insect biodiversity and positively impacted oil palm fruit set, bunch weight and productivity.*

Keywords: *Tirathaba rufivena, Bacillus thuringiensis, Elaeidobius kamerunicus*, fruit set.

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INTRODUCTION

Tirathaba rufivena Walker is known as oil palm bunch moth species in Indonesia and Malaysia. This moth is generally found mainly on newly planted areas with low fruit set or areas in which culled bunches are left behind (Wood and Ng, 1974). In Indonesia, *Tirathaba rufivena* is a major pest in oil palm plantations on peat and sandy soils, whereas is a lesser pest in mineral soils. Bunch moth infestations can significantly reduce the quantity of fresh fruit bunches, therefore impacting the quantity and quality of crude palm oil due to direct damage and increased rotten fruitlets and fruit bunches.

Tirathaba rufivena is classified under the Pyralidae family (Gallego and Abad, 1985). The life cycle of *T. rufivena* is about one month. Eggs are primarily laid on and/or within female and male inflorescences although eggs can be laid on all

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developmental stages of female inflorescences and bunches. After about four days, the eggs hatch into larvae and live for 16-21 days through 5 instars. The pupal phase is about 5-10 days while adult moths survive for 9-12 days (Chan, 1973; Hartely, 1979; Wood and Ng, 1974). Moths are active in the late afternoon and early evening (Sudharto, 2004).

In general, *T. rufivena* infests young mature palms (Basri *et al*., 1991). However, when palm growth is limited by environmental factor, as palm height in peat soils, the pest can also be found in older palms. Bunch moth caterpillars are capable of damaging the female inflorescences through the ripening stage (Darus and Basri, 2001). It causes feeding damage by creating holes either in male and female flowers or young to ripe fruits. The caterpillars damage the ripening fruits by feeding on the periderm. The damaged fruit may eventually fall to the ground prematurely or after being developed without kernels. The damaged bunches are usually covered by the caterpillar's faeces and silk (Yaakop and Manaf, 2015).

In the present study, *Bacillus thuringiensis* SC (soluble concentrate), with the active ingredient *Bacillus thuringiensis* subsp. *kurstaki* strain ABTS-351, was used as biological insecticide to control pests in oil palm. The efficacy of this selective bioinsecticide as well as the impact on oil palm productivity were assessed. *Bacillus thuringiensis* is a bacterium that produces a class of crystal proteins named δ-endotoxins, some of which selectively kill Lepidoptera larvae like those of *T. rufivena* (Hofte and Whiteley, 1989). In their native form, these crystals are composed of protoxins without insecticidal activity. However, in the high pH environment of the Lepidoperta larval midgut, the crystals solubilise and are metabolised into shorter polypeptides (27-149 kd) which have insecticidal properties. These toxins very rapidly interact with epithelium cell in the gut of Lepidoptera larvae creating pores (very small hole) in the membrane of the digestive tract. As a result, it disrupts the osmotic balance of cells. These cells become swollen and rupture eventually causing death to the insects (Hofte and Whiteley, 1989; Bahagiawati, 2002). Following ingestion and intoxication, larvae immediately become inactive, stop or cease feeding, and may start vomiting or stools become watery. The head of insects may also appear larger compared to its body size. Furthermore, the larvae become flabby, desiccate and die in a matter of a few days to a week. The bacteria causes the body content of insects to change into a brownish-black, red or yellow, and rot (Wainhouse, 2005; WHO, 1999).

The current management strategy for *T. rufivena* relies heavily on the application of chemical insecticides. Application of non-selective chemical insecticides, such as fipronil, over a long period negatively impacts the population and activity of *Elaeidobius kamerunicus*, which is the primary pollinating insect in oil palm plantations in Indonesia (Prasetyo and Susanto, 2012a; Prasetyo *et al*., 2013). Normally, overlapping developmental stages are present by the time all inflorescences and bunches have been attacked by *T. rufivena*. Therefore, frequent, repeated application of insecticides is recommended. *Bacillus thuringiensis* SC, as a selective, biological insecticide, can control this pest effectively while having an extremely limited impact on users, beneficial insects, and the environment. The primary objective of this study is to compare the effects of a year-long pest control strategy, either using a broad-spectrum chemical product (fipronil 50 SC) or selective insecticides, including *Bacillus thuringiensis* SC and Rynaxypyr 50 SC, on *T. rufivena* attack, number and activity of *E. kamerunicus*, insect biodiversity and the resulting impacts on oil palm fruit set and productivity.

MATERIALS AND METHODS

A one-year, long-term study of insecticide applications to control *T. rufivena* was conducted in oil palm plantations on peat soil in Indragiri Hilir, Riau Province, Indonesia from 25 February 2015, to 25 February 2016, on relatively young, 7-year old mature palms.

Experimental Design

The trial design was a solid block, completely randomed design (CRD) comprising an area of about 5-6 ha per treatment. Each treatment was represented by 10 replicates consisting of nine palms, one centre palm and eight adjacent palms. In order to minimise error that might be caused by cross contamination between treatments, four rows of palms at the edge of each adjacent block were not observed, though they were treated accordingly to sustain treatment consistency. Each sample palm and all associated fruit bunches were tagged for data collection.

Treatments

Four treatments consisted of three types of insecticide applications were compared to an untreated control block. They are fipronil 50 SC alone, *Bacillus thuringiensis* SC alone, and an alternating rotation of Rynaxypyr 50 SC with *Bacillus thuringiensis* SC (rotation repeated three times during the study) (*Table 1*). Treatments were applied every two weeks for a period of nine months using a backpack mist blower at a volume of 400-500 litres ha^{-1}. The insecticide spray was directed to inflorescences and fruiting bunches with partial cover of the plant canopy.

TABLE 1. TREATMENTS

Treatment	Concentration (ml/15 litres of water)
Fipronil 50 SC	37.5
Bacillus thuringiensis SC	30
Rotation: *Bacillus thuringiensis* SC (3 times) followed by Rynaxypyr 50 SC (1 time)	30 (*Bacillus thuringiensis* SC) 15 (Rynaxypyr 50 SC)
Untreated control	-

Assessments

Variables measured were the intensity of *T. rufivena* attack, the number of *E. kamerunicus* visiting male and female inflorescences, the total weevil population per hectare, and harvest data; including bunch weight, fruit set, and the quantity of any stages of *T. rufivena* in each bunch. In addition to that, insect biodiversity within treated and untreated blocks was also measured six times between February and September 2015.

Intensity of* T. rufivena *attack. Observations were made on a sample of 90 palms for each treatment every month. Intensity of *T. rufivena* attack was calculated using a scoring system based on the following formula:

$$IS = \frac{\Sigma (n \times v)}{N \times V} \times 100\%$$

IS = intensity of *T. rufivena* attack
n = number of sample palms in the selected category
v = the selected category
N = the total number of sample palms
V = the value of the largest category

Categories:
0 = no symptoms of attack (0%)
1 = mild attacks, bunches attacked <25%
2 = moderate attack, bunches attacked 25%-50%
3 = somewhat heavy attack, bunches attacked 50%-75%
4 = severe attacks, bunches attacked 75%-100%

The efficacy values of the insecticides were determined using the Abbott formula (1925) as follows:

$$\text{Efficacy value (\%)} = \left(1 - \frac{\text{\% Intensity of } T.\ rufivena \text{ attack in a treatment}}{\text{\% Intensity of } T.\ rufivena \text{ attack in untreated control}}\right) \times 100\%$$

***Population and activities of* E. kamerunicus**. The population of *E. kamerunicus* was calculated using the method described by Susanto *et al*. (2015) based on the number of weevil visits on anthesising male and female inflorescences per hectare. For every anthesising male inflorescence on sample palms, taking three spikelet flowers were covered using a transparent plastic sheet to observe the approximate number of weevils in each inflorescence assesses the number of weevils. For every anthesising female inflorescence, a yellow sticky trap, measuring 2 x 30 cm, was installed around the inflorescence for 24 hr. The number of weevils caught in the sticky trap indicates the number of weevils visiting each female inflorescence. All assessments were conducted on monthly basis.

Oil palm productivity. Each ripened oil palm bunch from treated and untreated palms was harvested every seven days or according to the harvesting rotation of the estate. Each fruit bunch harvested was weighed, analysed for fruit set, and observed for the number of *T. rufivena* at each developmental stage.

Insect biodiversity. The biodiversity of insects in the treatment block was assessed every month using three different types of traps; malaise traps, yellow tray traps and manual insect nets. A malaise trap net was installed at the centre of each treatment block for a period of 24 hr to trap flying insects. Yellow tray traps were filled with water and placed on the side of palm circles to capture insects at ground level. There are 20 yellow tray traps set per treatment block for a period of 24 hr. On the other side, sweep nets were used with at least 10 sweeps on 20 palms to target the insects among low growing plants around palms.

Phytotoxicity

Each sample palm and its surrounding palms from the treated blocks were observed for phytotoxicity or abnormal symptoms. The condition of palms in each treatment was compared to palms in the untreated control block especially in malformation and colorisation of leaves.

Data Analysis

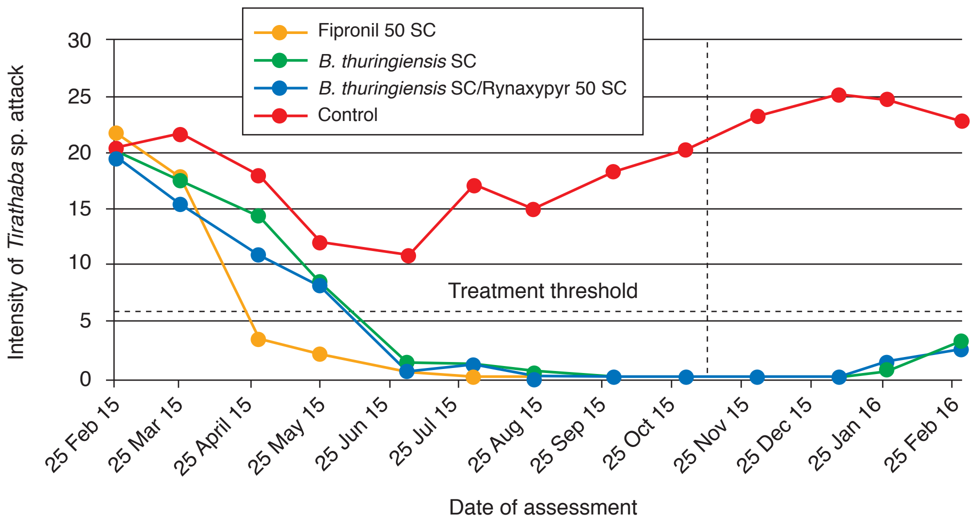
All data were subjected to analysis of variance using SAS 9.0 software. At which it is applicable, means are separated using Tukey's procedure (P <0.05).

RESULTS AND DISCUSSIONS

Intensity of *T. rufivena* Attack

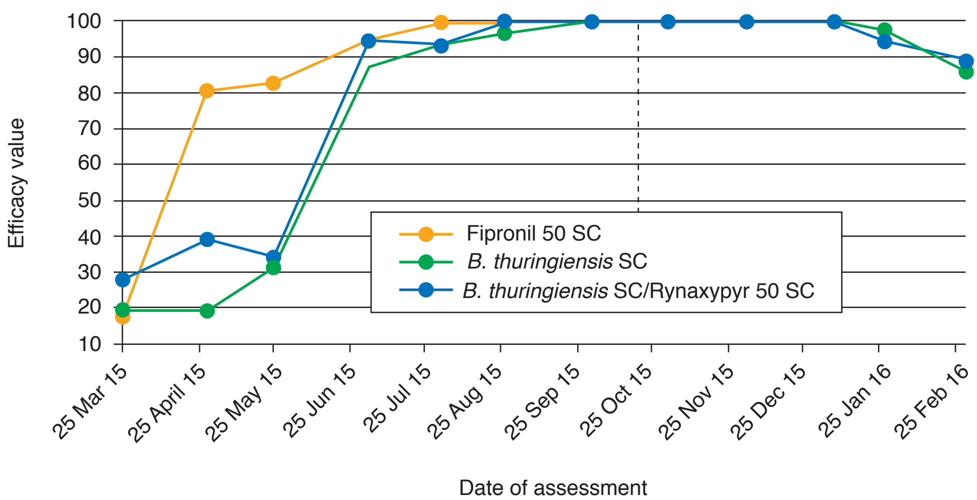
Before the treatments were initiated, the present intensity of *T. rufivena* attack at the trial block reached more than 20% and the symptoms were observable from inflorescences to ripe fruit bunches. From multiple sampled bunches, *T. rufivena* were found in all development stages which indicated an overlapping stages of the pest. However, after the application of insecticides reduced the intensity of *T. rufivena* below the <5% economic threshold; within two months for fipronil 50 SC and within four months either for *Bacillus thuringiensis* SC alone or *Bacillus thuringiensis* SC in rotation with Rynaxypyr 50 SC. Meanwhile, the intensity of *T. rufivena* in the untreated control treatment remained high. In accordance with the requirements of the Pesticide Commission in Indonesia, the efficacy value was more than 70% (*Figures 1* and 2). These mean that all insecticides were effective in controlling *T. rufivena* in the field.

Previous observation has suggested that the key to successfully controlling overlapping developmental stages of *T. rufivena* is by breaking the pest life cycle through the repeated application of insecticides at regular intervals, such as the implemented 14-day application frequency. The data shown above are consistently support the previous results. Larvae of *Tirathaba* sp. consist of 5 instars with a two- to three-week biological life cycle (Yaakop and Manaf, 2015) during which larvae are active inside of the oil palm bunch and fruit. Consequently, it is difficult to ensure



Note: Final insecticide application made at end of October 2015.

Figure 1. Intensity of T. rufivena *attack in each treatment.*



Note: Final insecticide application made at end of October 2015.

Figure 2. Efficacy value of the insecticides in every month of assessment.

larvae are exposed to the insecticides. This study illustrates that regular and continuous insecticide applications suppress new attack symptoms by gradually reducing populations of larvae and pupae of *T. rufivena* until no longer found within each bunch (*Figure 3*). Basri *et al*. (1991) and Lim (2012) reported similar results at which palms were treated multiple times with *Bacillus thuringiensis*. Eloja and Abad (1981) also examined the effect of the insecticides diazinon and triazophos (0.08% of active ingredient), trichlorphon (0.12% of active ingredient), pirimiphos-methyl (0.08% of active ingredient) and azinphos-ethyl (0.05% of active ingredient) with all insecticides significantly reduced *Tirathaba* sp. attack by more than 50% after at least three repeated applications. Furthermore, spraying at least two repeat applications of Thiodan® with 0.04% of active ingredient was shown to reduce the population of *Tirathaba* sp. (Onn, 1972).

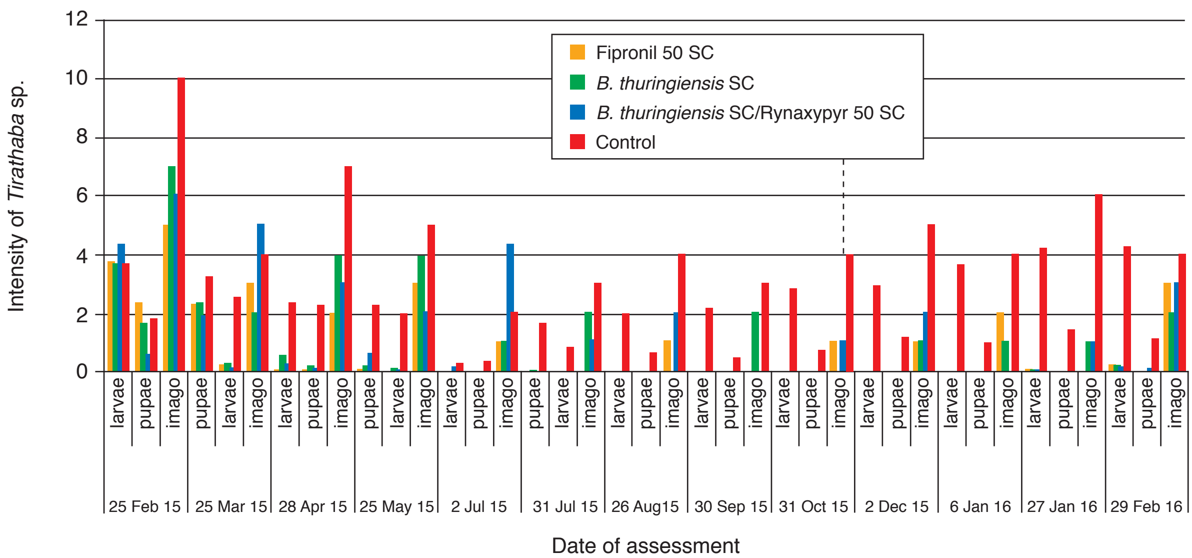
In insecticide treatment blocks, adult moths were the most common developmental stage of *T. rufivena* caught by insect traps, after five months of application when pupae and larvae populations were significantly diminished. *T. rufivena* belong to the nocturnal insect group that actively flies at night. Therefore, the trapped moths of *T. rufivena* were most likely flown or were blown in from the surrounding areas adjacent to the study field blocks and/or from the untreated control block.

After being regularly applied, three months application of fipronil 50 SC and five months application of *Bacillus thuringiensis* SC and *Bacillus thuringiensis* SC in rotation with Rynaxypyr 50 SC has reduced the intensity of *T. rufivena* attacks to be 0, indicating that all bunches had finally no infestation of pest. The intensity of *T. rufivena* attacks were then remained well below the economic threshold (<5) for all treatments through the end of the 12-month observation period. Symptoms began to reappear in the 11th month of the study, two months after the final application of each product. These results are consistent with the result of Ming (2015) in Sarawak, Malaysia, in which applications of *B. thuringiensis* maintained clean bunches without *T. rufivena* through three months after repeated application.

Population and Activity of *E. kamerunicus*

Fipronil 50 SC had a negative impact on adult populations, reproduction and pollinating activity of the African pollinating weevil, *E. kamerunicus* although it was the quickest insecticide to reduce the intensity of *T. rufivena* attacks. *Figure 4* shows fipronil 50 SC treatments causing a devastating population decline of weevils in the first month of observation through the ninth month of application. In comparison to the *Bacillus thuringiensis* SC treatment or its alternating rotation with Rynaxypyr 50 SC, weevil populations and reproduction remained positive and relatively constant over the 12 months of study similar to the control block.

Daytime insecticide applications directly exposed the adult weevils since the weevils are active in the anthesising male and female inflorescences during the day (Adaigbe *et al*., 2011). Prasetyo *et al*. (2013) and Ahmad *et al*. (2009) conducted *in vivo* studies, later confirmed in the field by Lopez *et al*. (2014), on the impact of *B. thuringiensis* on *E. kamerunicus* survival and proliferation, which illustrated that repeated applications of *B. thuringiensis* do not affect weevil populations overall or effect the number of adult weevils visiting anthesising oil palm inflorescences. Furthermore, Ahmad *et al*. (2012) tested *B. thuringiensis* from



Note: Final insecticide application made at end of October 2015.

Figure 3. Number of larvae, pupae and moths of T. rufivena *per sample bunch in each treatment for each assessment date.*

different registered products and similarly did not observe significant differences in weevil populations five days after application.

In another study, Purba *et al*. (2012) stated that spraying broad-spectrum insecticides could negatively reduce the population of *E. kamerunicus* between 10%-20%. Lopez *et al*. (2014) also noted that the application of some chemical insecticides caused disappearance of the weevils relatively quickly within one to three days after spraying. *E. kamerunicus* mortality of up to 100% was observed one day after application when treated with the chemical cypermethrin (Ahmad *et al*., 2009; 2012) or nearly 100% for trichlorfon (Kok *et al*., 2010). Even thiocyclam hydrogen oxalate has been reported to lower populations of *E. kamerunicus*, *E. subvittatus*, *E. plagiatus* and *E. singular* (Tuo *et al*., 2011a). Other insecticides that are reported to reduce the population of *E. kamerunicus* weevils, but not as severely, are imidacloprid (Hanbal, 2009) and indoxacarb (Kok *et al*., 2010). Insecticides containing Rynaxypyr (Kok *et al*., 2010) or TMOF (Trypsin-modulating oostatic factor) for mosquito eradication (Omar, 2011) are reported to be relatively harmless on *E. kamerunicus*.

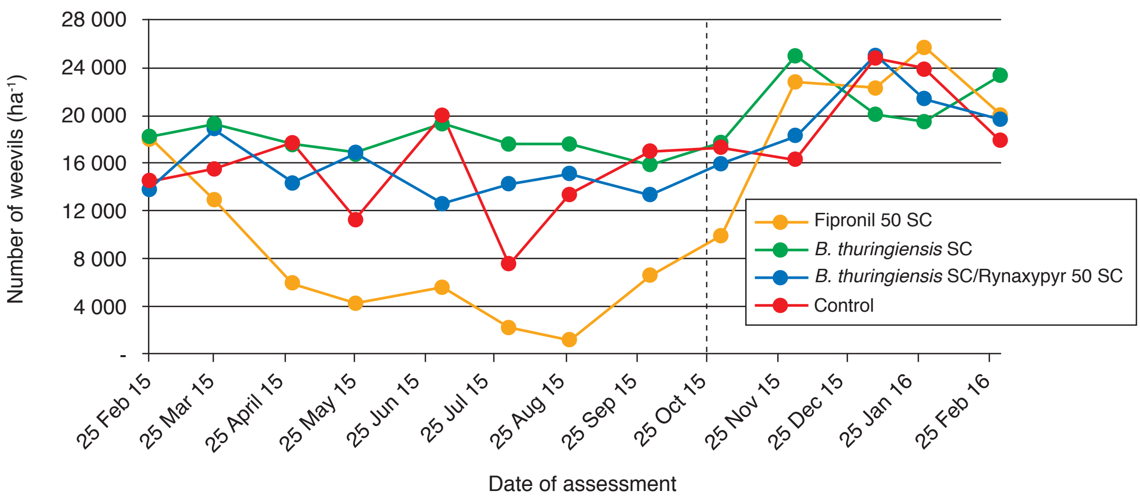
The population of *E. kamerunicus* in the block treated by fipronil 50 SC began to normalise in the 10th month of observation after insecticide applications were suspended through the 9th month. This illustrates weevils returning to visit the anthesising male inflorescences and breeding, suggesting minimal residual impact. Hutauruk *et al*. (1985) observed weevils on male inflorescences at least two days after an application of chemical insecticides. The resurgence of weevil populations, therefore, is expected due to the insect's relatively short life cycle: 11-21 days in Malaysia (Syed, 1982), 10-22 days in West Java, Indonesia (Kurniawan, 2010), and even nine days in West Africa (Tuo e*t al*., 2011b).

Additionally, fipronil 50 SC applications reduced the number of weevils visiting anthesising female inflorescences (*Figure 5*). According to Prasetyo and Susanto (2012b), a minimum of 125 weevils per trap is required on anthesising female inflorescence to achieve greater than 75% oil palm fruit set. The number of weevils visiting female inflorescences decreased through five months of treatment with fipronil 50 SC resulting in below 125 weevils per trap until the final application in the ninth month. In contrast, *Bacillus thuringiensis* SC or its alternating rotation with Rynaxypyr 50 SC created fluctuations in weevil populations, although assessments tended to have greater than 125 weevils per trap. The low impact of these pesticides on weevil populations had a profound influence on fruit set and total yield.

Fruit Set and Oil Palm Productivity

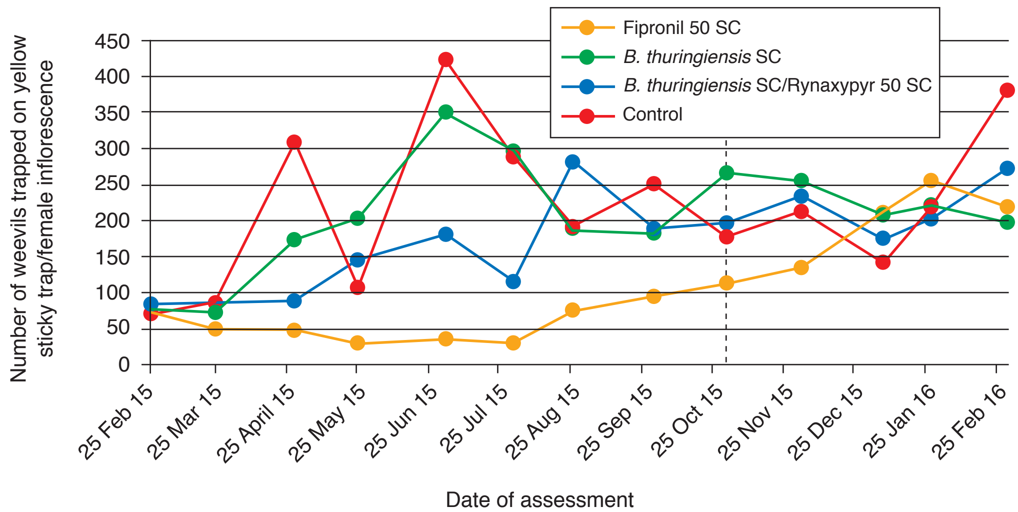
Following the correlation between treatment and number of weevils visiting infloresence, the impact of number of weevils to the fruit set were then being assessed. As the development of an oil palm bunch starting from pollination through to harvest takes about six months (Hidayat *et al*., 2012), fruit set and productivity was collected through the trial (*Figure 2* and *Table 3*), and analysed in the final six-month of the study (*Table 2*). Fruit set over 75% is defined as good fruit set (Susanto *et al*., 2007).

The high number of weevils found visiting anthesising female inflorescence in the *B. thuringiensis* treatment (*Figure 5*) was found to be followed by the relatively high value of fruit set at over 75% during the last six months (*Figure 6*). In contrast, the fipronil treatment block did not exceed 70% fruit set through the duration of the



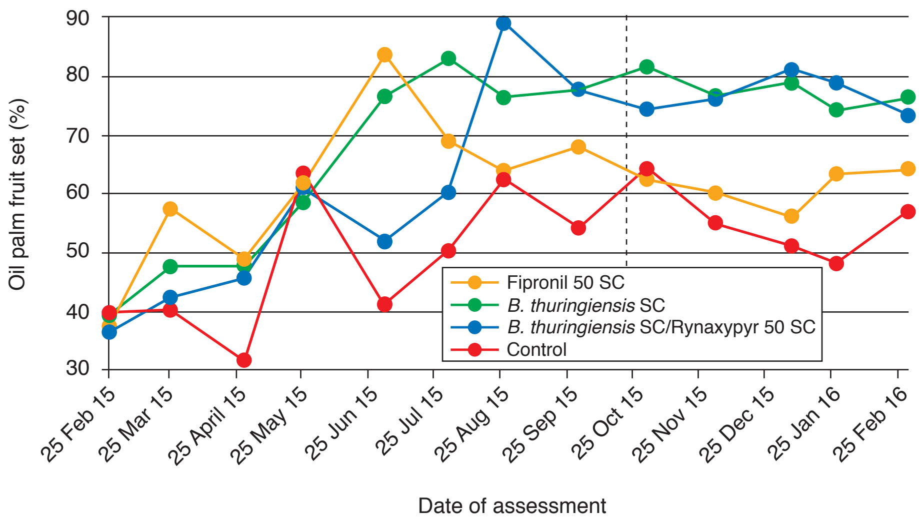
Note: Final insecticide application made at end of October 2015.

Figure 4. The population of E. kamerunicus *in each treatment.*



Note: Final insecticide application made at end of October 2015.

Figure 5. Number of E. kamerunicus *weevil visit on anthesising female inflorescence in each treatment using yellow sticky trap.*



Note: Final insecticide application made at end of October 2015.

Figure 6. Oil palm fruit set in each treatment.

study (*Figure 6*). This proves that the decrease of *E. kamerunicus* population has an impact on the reduction of oil palm fruit set; though requirements of *E. kamerunicus* population may depend on the geographical location in Indonesia (Prasetyo and Susanto, 2012b).

In contrast to other research mentioned above, Omar (2011) reported that the population of *E. kamerunicus* may not be reduced in the field; if chemical non-selective insecticides are applied once only. By a repeated and high frequency applications, the declining *E. kamerunicus* population could be substantial and it will then affect oil palm fruit set and productivity. In the control treatment, although the number of weevils visiting anthesising female inflorescence was relatively high, oil palm fruit set was considerably low due to *T. rufivena* infestation.

During the final six months of the study, the average bunch weight from the *Bacillus thuringiensis* SC treatment block was the highest at 2.92 kg and was not significantly different from its rotation with Rynaxypyr 50 SC at 2.51 kg. Average bunch weight in the fipronil 50 SC treatment block was significantly lower at 2.43 kg while in the untreated control treatment, without insecticide application, was only 1.65 kg (*Table 2*). Similarly, these significant differences resulted in the productivity of oil palm with the highest production in the *Bacillus thuringiensis* SC treatment being the highest followed by its rotation with Rynaxypyr 50 SC, fipronil 50 SC, and then the control treatment, producing 1145.11 kg, 983.33 kg, 930.16 kg, and 684.59 kg, respectively, (*Table 2*). While there were significant differences in a number of productivity parameters observed, the

TABLE 2. THE ASSESSMENT OF OIL PALM PRODUCTIVITY DURING THE LATTER SIX MONTHS OF THE STUDY (end of August 2015 to end of February 2016) FROM 90 PALM SAMPLES

Treatment	Number of bunches	Average bunch weight (kg)	Oil palm yield (kg)
Fipronil 50 SC	382a	2.43b	930.16b
Bacillus thuringiensis SC	392a	2.92a	1145.14a
Bacillus thuringiensis SC/Rynaxypyr 50 SC	392a	2.51ab	983.33ab
Control	416a	1.65c	684.59c

Note: Number in same coloumn followed by same word shows significantly different based on Tukey's test, alpha 5%.

number of bunches harvested from 90 palm samples was not statistically different. This indicates that *T. rufivena* undermines production efficiency, but not bunch number (*Appendix 1*).

Despite the effective pest control and enhanced yields resulting from *Bacillus thuringiensis* SC treatments, the total yield could be considered relatively low. The number of harvested bunches is actually influenced by palm physiology which is built up by the environmental or biotic stress conditions in the previous two year's growth period (Lubis, 2008). If palms are grown under stressful conditions (*e.g.* low available moisture, extreme temperatures and/or poor fertility), primordial differentiation trends towards male inflorescences rather than female inflorescences, thus reducing fruiting bunch emergence. If the existing bunch undergoes good pollination and is not attacked by *Tirathaba* or *Marasmius* during development, it is possible that the average bunch weight will increase over time (Hidayat *et al*., 2012). In the present study, *Bacillus thuringiensis* SC positively impacts oil palm productivity by reducing the intensity of *T. rufivena* attacks while not affecting weevil populations compared to fipronil 50 SC.

Insect Biodiversity

Ecologically, the application of the chemical insecticide fipronil 50 SC has a negative impact on the presence of insect communities compared to the biological insecticide *Bacillus thuringiensis* SC. Although the number of insects was relatively similar between treatments (*Figure 7*), the number of different insect families found in the fipronil 50 SC treatment block was the lowest after the first application. *Bacillus thuringiensis* SC has a narrow insecticidal spectrum, only killing insects from the Lepidoptera order. Therefore, the biodiversity indices for biological insecticide treatments were expectedly unchanged throughout the observation period. In the control treatment without insecticide application, the number of insects, number of different families and insect biodiversity index were relatively constant except for a decline in the sixth month and quite high in the seventh month.

Research conducted by Ahmad *et al*. (2009; 2012) using several formulations of *B. thuringiensis* demonstrated that the insecticide had minimal impact on predatory or parasitoid insects particularly associated with the beneficial plant *Cassia cobanensis* in oil palm plantations. The parasitoids exposed to *B. thuringiensis* and Cypermethrin most commonly found by the authors were *Dolichogenidea metesae, Goryphus bunoh* and *Brachymeria carinata*. The dose rate of *B. thuringiensis* 6.4 x 10^{11} cfu ml^{-1} (100 times higher than the recommended dose rate) caused only 16% mortality compared with Cypermethrin, applied at 7.5%, which resulted in 100% mortality of beneficial parasitoids. In contrast, *B. thuringiensis* spraying at concentrations less than 6.4 x 1010 cfu ml^{-1} did not kill parasitoid insects through 13 days of observation.

Phytotoxicity

Through nine months of bi-weekly application and 12 months of assessment, the application of tested insecticides at dose rates according to *Table 1* caused no phytotoxic symptoms for all treated palms. These observations indicate that the various tested insecticides were safe for oil palm.

CONCLUSION

This study illustrates the benefits of utilising selective insecticides for optimising oil palm yields through control of *T. rufivena* and mitigating the impact of pest control options on African pollinator weevil populations. *Bacillus thuringiensis* SC and its rotation with Rynaxypyr 50 SC increased oil palm yields (*Table 2* and *Appendix 1*) with effective bunch moth control within four months (*Figures 1* to *3*) without impacting weevil number (*Figures 4* and *5*) and thus, pollination (*Table 2*). Additionally, the low impact of *Bacillus thuringiensis* SC on beneficial insects (*Figure 7*) may have maintained populations of predatory insects, enhancing complementary biological insect control to suppress and/or prevent potential outbreaks of other oil palm pests. In stark contrast, application of the fipronil 50 SC effectively controlled *T. rufivena*, but negatively impacted

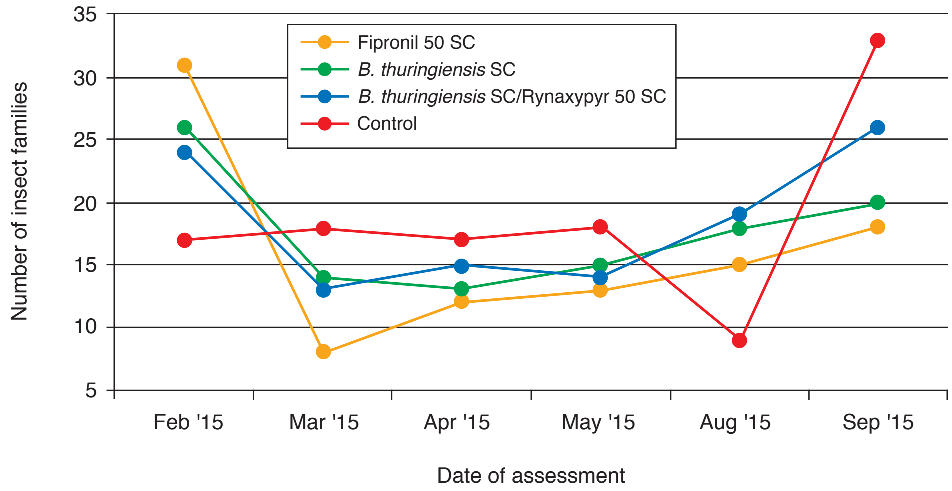


Figure 7. Number of insect families observed at each treatment block.

adult populations of *E. kamerunicus*, then reduce oil palm fruit set and productivity. Using selective pesticides, like *Bacillus thuringiensis* SC, can be a key tool in maximising oil palm yields while promoting sustainability and environmental stewardship.

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Appendix 1

TABLE 1. ASSESSMENT OF OIL PALM PRODUCTIVITY.

Assessments	Treatment	Month of observation											
		Mar '15	Apr '15	May '15	Jun '15	Jul '15	Aug '15	Sep '15	Oct '15	Nov '15	Dec '15	Jan '16	Feb '16
Number of	Fipronil 50 SC	105a	67a	89a	111a	61a	80a	68a	56a	55a	66a	46a	62a
harvested bunches	*Bacillus thuringiensis* SC	76b	65a	95a	98a	76a	65a	70a	55a	62a	66a	54a	60a
(bunches)	*Bacillus thuringiensis* SC												
	Rynaxypyr 50 SC	91a	69a	91a	109a	79a	73a	71a	56a	60a	67a	56a	60a
	Control	6 b	61a	85a	91a	63a	69a	75a	66a	57a	71a	66a	60a
Average bunch	Fipronil 50 SC	2.15a	2.10ab	2.42a	1.93a	2.11a	1.85b	2.03b	2.30b	1.74b	2.99a	2.85a	2.58b
weight (kg)	*Bacillus thuringiensis* SC	2.24a	2.50a	2.53a	1.85a	2.01a	2.41a	2.71a	3.10a	2.62a	3.27a	2.84a	2.78a
	Bacillus thuringiensis SC												
	Rynaxypyr	1.52b	1.66b	1.68b	1.31b	1.37b	1.90ab	2.32ab	2.06b	2.52a	2.68b	2.78a	2.71a
	Control	1.30b	1.86ab	1.49b	1.23b	1.53ab	1.59b	1.53c	1.22c	1.58b	1.88c	1.92b	1.58c
Oil palm	Fipronil 50 SC	225.5a	140.6a	215.7a	214.0a	128.5a	148.0a	138.2b	128.8b	95. b	197.6a	131.0b	159.7a
productivity (kg)	*Bacillus thuringiensis* SC	169.9ab	162.2a	240.7a	181.3a	152.8a	156.7a	189.7a	170.3a	162.2a	215.6a	153.3a	167.0a
	Bacillus thuringiensis SC												
	Rynaxypyr 50 SC	138.0b	114.3b	153.0b	142.7b	108.0ab	138.5a	164.5ab	115.5b	151.2a	179.6a	155.5a	162.8a
	Control	86.0c	113.4b	126.7b	112.3b	96.2b	109.9a	114.6b	80.4c	90.2b	133.7b	126.7b	94.7b

Note: The same letter after the numbers in the same column did not indicate a significantly different by Tukey test at significant level 95%.
Treatments were intiated on 25 February 2015 and continued for nine months until 25 November 2015. Values are the average of 90 palm samples.